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The impact of manure production rights on capital investment in the Dutch pig sector

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Abstract
In this paper the effect of manure production rights on investment decisions of Dutch pig farmers is examined. A dynamic optimization model of investment that explicitly takes zero investments into account is augmented by a constraint on production arising from the introduction of manure production rights. In the theoretical model it is shown that such a constraint has a reducing effect on investment. The presence of this constraint is tested for using GMM structural break tests. The results provide evidence for the hypothesis that manure production rights have reduced investments through its effect on production.

Keywords: Investment, manure production rights, Euler equation, GMM, structural break testing, panel data, pig farms

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Introduction

Since the 1950's the Dutch pig sector has witnessed a rapid growth. In this period the number of pigs rose from around 2 million pigs in 1950 to about 16 million in the mid-nineties. What also grew rapidly was a surplus of manure produced by this increasing number of pigs. In order to curb this manure surplus, the Dutch government implemented a number of environmental policies in the 1980's and 1990's. During the first period of legislation, which lasted from 1984 to 1986, expansion of production was directly restricted by a number of prohibitive rules. However, due to a large use of exceptional dispositions and a possibly weak control system this law did not achieve its objectives. A second period of agri-environmental legislation began in 1987 with the introduction of a system of non-tradable manure production rights. In 1994 legislation was revised and the manure production rights became tradable. Given the close technical relation between the amount of manure produced (total of manure production rights) and the total production level, restrictions on manure production also implied an (indirect) constraint on pig production.

An argument often brought forward against quantitative restrictions on production (e.g. supply quota) is that they hamper structural development. Since farmers cannot expand their farm business, expansionary investments are not profitable and the total amount of investments is reduced. A consequence of lower investments is that the speed of innovation is reduced, deteriorating the long-run productivity of the sector (Richards and Jeffrey, 1997). Concern about reduced investments was one of the arguments for the Dutch government to make manure production rights tradable in 1994, since reduced investments also implied that investments that contributed to solving the manure problem were reduced (LNV, 1996).

Whether output was restricted by the system of manure production rights in the period 1987-1996 is uncertain. Although the growth in pig numbers was halted and investment was somewhat lower than before, it is not well understood whether farms were output constrained or not. The quantity of manure production rights was allotted on the basis of historical production levels which farmers had to indicate themselves. Farmers may have come up with numbers based on maximum production capacity instead of historical production levels, thus creating future possibilities for expansion of production (Frouws, 1994). Furthermore, the decrease in investment may have had other causes. Low output prices in this period may have reduced expected gains from investment or deteriorated the financial situation of farmers.

The objective of this paper is to test whether manure production rights constrained capital investment in the Dutch pig sector over the period 1987-1996 through an indirect constraint on production. In order to address this research question an inter-temporal model of investment is developed. For the period 1987-1996, in which manure production rights may have limited manure production on individual farms, the model is augmented by a (potentially binding) constraint on pig production. Whether this constraint was indeed binding is tested for empirically. From the inter-temporal optimization problem of farmers, necessary first-order conditions are derived and solved for analytically using the Euler equation method. The combined first-order condition is estimated directly using the Generalized Method of Moments (GMM) estimation technique. In order to test for the presence of a binding constraint on production a GMM structural stability test is used (Hall, 1999).

The model presented in this paper differs from previous empirical Euler equation studies (e.g. Pindyck and Rotemberg, 1983; Whited, 1998) in the way zero investments are taken into account. Previous studies consider zero investment to be optimal when the marginal benefits of investing equal the purchase price of capital. Following theoretical work by Chavas (1994), in this paper it is assumed that investment is zero for the range in which the marginal benefits

of investing are equal to or smaller than the purchase price of capital. From the theoretical model regimes for positive and zero investments are derived.

The contributions of this paper are twofold. First, a constraint on production is modeled explicitly into an Euler equation framework. Using structural stability tests for GMM this constraint is tested for. Second, the empirical Euler equation framework is extended to include a threshold for investment, in order to explain zero investments explicitly. The paper is built up as follows. In the next section a short overview of Dutch manure policies in the 1980's and 1990's is given. Section three develops the theoretical framework of this paper. In section four the empirical model, the testing procedure and other estimation issues are discussed. A description of the data is given in section five. Results are presented in section six and conclusions are drawn in section seven.

Manure policies

Growing manure surpluses in Dutch intensive livestock production have led to increasing environmental concerns over the last two decades. In order to curb these manure surpluses the government implemented a number of environmental policies in the 1980's and 1990's. For an overview of the various elements of these agri-environmental policies see Haerkens and Walda (1994) and Heisterkamp and Bruil (1998). In this section an overview is given of those policy elements that aimed at restricting manure production[1].

1984-1986

In 1984 the first legislation directly aiming at controlling manure production in the intensive livestock sector was introduced. The *Interimwet beperking varkens- en pluimveehouderijen* prohibited the expansion of existing farms in the south and east of the Netherlands (so-called concentration regions) by more than 10% and by more than 75% for farms in other parts of

the country. Furthermore, it was not possible to establish a new farm with intensive livestock production. However, due to a large use of exceptional dispositions and a possibly weak control system this law did not achieve its objectives. In the period 1984-1987 the number of pigs increased by 28% (Algemene Rekenkamer, 1990). Therefore, the limiting effects of this law on production and investment are assumed to be minimal.

1987-1993

In 1987 phosphate based manure production rights were introduced in order to restrict the production of manure. Farms received manure production rights proportional to 125 kg phosphate per hectare (acreage based manure production rights). Moreover, each farm was allotted a reference quota of manure production rights based on the inventory of animals and standards for the manure production by animal category. By determining the area of farmland owned or long term leased, the difference between the acreage based phosphate rights and the reference quota could be calculated in order to make a distinction between manure surplus and manure deficit farms (i.e. farms with manure production larger or smaller than 125 kg phosphate per hectare). Until 1994 trade in manure production rights was prohibited. Only in very special occasions (e.g. with marriage or heritage or the transfer of a complete farm) farmers could obtain additional manure production rights. Buying additional land increased the amount of acreage based manure production rights, but this only allowed an increase in manure production for manure deficit farms. Most pig farms however, were typically manure surplus farms and therefore could not expand manure production by buying additional land.

1994-1996

In 1994 new legislation was enacted that allowed trade of manure production rights to some extent. The amount of acreage based manure production rights could not be traded. Pig based

manure production rights could be used for manure production of any type of animal but not vice versa. Furthermore, geographical restrictions on trade were set. Farmers within one of the two concentration regions could trade within their region, but could not buy manure production rights outside their region. Moreover, from the production rights transferred, 25% of them were siphoned by the government. In addition, a farmer who acquired additional manure production rights had to certify that he had either sufficient land to apply his total amount of manure or had a manure disposal contract with another farm. In the period 1994-1996, 6.4% of the total amount of tradable production rights was traded (LNV, 1996).

Theoretical framework

In this section a theoretical model of Dutch pig farmers optimizing over time is developed. Making assumptions on the objective of farmers and the constraints faced in optimizing, necessary first-order conditions (f.o.c.'s) for optimal investment are derived. Using the so-called Euler equation approach these f.o.c.'s are combined into a necessary optimality condition holding over two subsequent time periods. Examples of the Euler equation approach can be found in e.g. Pindyck and Rotemberg (1983) and Whited (1998).

The objective of pig farmers is assumed to be the maximization of the expected stream of future cash flows at time t:

$$PV_{h,t} = E_{h,t}\left[\sum_{j=0}^{\infty} r_{t+j} CF_{h,t+j}\right] \tag{1}$$

where $PV_{h,t}$ is the expected present value for farm h at time t, $E_{h,t}$ is the expectations operator conditional on the information available to farm h at time t and r_{t+j} is the discount rate which is defined as:

$$r_{t+j} = \prod_{i=1}^{j} (1 + r_{t+i})^{-1} \qquad \text{and} \qquad r_t = 1$$

where r_{t+i} is the real interest rate. Equation (1) is maximized subject to the following constraint:

$$CF_{h,t} = p_t F\left(X_{h,t}, K_{h,t}, Z_{h,t}\right) - w_t X_{h,t} - y\left(I_{h,t}\right) - p_t^I \cdot I_{h,t} \tag{2}$$

Equation (2) defines cash flows for farm h in year t as revenues of production minus variable costs, adjustment costs and investment expenditure. Total production of pig output in year t, given by the production function $F(.)$, depends upon a vector of variable inputs $X_{h,t}$, an aggregate quasi-fixed capital input $K_{h,t}$, and a vector of fixed factors $Z_{h,t}$. Output price is p_t and w_t denotes a vector of input prices. The adjustment cost function y is dependent on the size of gross investments in year t, $I_{h,t}$. The following assumptions on the adjustment cost function are made: y is non-negative, is zero at zero investment and convex in investment. Examples of adjustment costs are learning costs, costs of restructuring the production process, administrative costs in obtaining building or environmental licenses, the value of time spent on preparing the investment, fees paid to banks in order to get a loan etc. Investment expenditure consists of the expenditure on new capital goods where p^I_t denotes the unit purchase price of capital. The capital stock is defined by

$$K_{h,t} = I_{h,t} + (1-d)K_{h,t-1} \tag{3}$$

stating that the current capital stock consists of last year's capital stock, corrected for depreciation (d is the depreciation rate), plus current investment. In this study, investment is assumed to be greater than or equal to zero[2].

Manure policy aims at restricting the amount manure produced. Given the close relationship between the physical pig output and the amount of manure produced (total of manure production rights), a system of manure production rights indirectly limits physical production. The effect of manure production rights on investment is therefore modeled by a

potentially binding constraint on production. Production cannot exceed an upper bound $\overline{F}_{t,h}$, which depends upon the quantity of manure production rights a farm has:

$$F(X_{h,t}, K_{h,t}, Z_{h,t}) \leq \overline{F}_{h,t} \tag{4}$$

This constraint is included in the model. Note however that in years in which manure policies were absent (1980-1983) or not assumed to be constraining production (1984-1986), the constraint is not binding and the corresponding Lagrange multiplier is zero, removing the constraint for these years.

The problem given by the set of equations (1)-(4) can be summarized by considering it as a dynamic programming problem with corresponding Bellman equation:

$$PV_t(K_{t-1}) = \max_{x_t, I_t} \left\{ \begin{array}{l} p_t F(X_t, I_t + (1-d)K_{t-1}, Z_t) - w_t X_t - y(I_t) - p_t^I \cdot I_t \\ + E_t[r_{t+1} PV_{t+1}(I_t + (1-d)K_{t-1})]; \\ X_t > 0, I_t \geq 0, F(X_t, K_t, Z_t) \leq \overline{F}_t \end{array} \right\} \tag{5}$$

where individual farm subscripts h are left out for convenience. The present value at time t depends upon the given state K_{t-1}. In period t the control variable I_t is set to an optimal level such that in period $t+1$ the state variable is K_t. In order to take the restriction on production (4) into account and to obtain first-order conditions the Lagrangian is written:

$$\begin{aligned} L = {} & p_t F(X_t, I_t + (1-d)K_{t-1}, Z_t) - w_t X_t - y(I_t) - p_t^I \cdot I_t \\ & + E_t[r_{t+1} PV_{t+1}(I_t + (1-d)K_{t-1})] + m_t[\overline{F}_t(\cdot) - F(X_t, I_t + (1-d)K_{t-1}, Z_t)] \end{aligned} \tag{6}$$

Note that the Lagrange multiplier m_t differs by farm and over time. From the Kuhn-Tucker conditions for $I_t \geq 0$ the following first-order necessary conditions for investment are derived:

$$I_t > 0 \qquad (p_t - m_t)\frac{\partial F_t}{\partial K_t} + E\left[r_{t+1}\frac{\partial PV_{t+1}}{\partial K_t}\right] = p_t^I + \frac{\partial y_t}{\partial I_t} \tag{7a}$$

$$I_t = 0 \qquad (p_t - m_t)\frac{\partial F_t}{\partial K_t} + E\left[r_{t+1}\frac{\partial PV_{t+1}}{\partial K_t}\right] \leq p_t^I + \frac{\partial y_t}{\partial I_t} \tag{7b}$$

These optimality conditions for both regimes provide a theoretical explanation for observed positive and zero investment. Equation (7a) states that if a farmer invests, investments are

made until marginal benefits and marginal costs of investment are equated. The marginal benefits of investing consist of the marginal value product, $(p_t - m_t)\frac{\partial F_t}{\partial K_t}$, and the discounted expected dynamic shadow price of capital, $r_t E\left[\frac{\partial PV_{t+1}}{\partial K_t}\right]$, which reflects the change in the present value due to an increase of the capital stock. Marginal costs of investment consist of marginal adjustment costs $\partial y_t / \partial I_t$ and the unit purchase price of capital p^I_t. No investment is undertaken when the marginal benefits of investing are less than marginal costs of investment. This is given by equation (7b).

Differentiating either the Lagrangian in (6) or the Bellman equation in (5) with respect to state variable K_{t-1} yields:

$$\frac{\partial L}{\partial K_{t-1}} = \frac{\partial PV_t}{\partial K_{t-1}} = (1-d)\left\{(p_t - m_t)\frac{\partial F_t}{\partial K_t} + E\left[r_{t+1}\frac{\partial PV_{t+1}}{\partial K_t}\right]\right\} = 0 \tag{8}$$

Using equations (7) this condition can be rewritten to:

$$I_t > 0 \qquad \frac{\partial PV_t}{\partial K_{t-1}} = (1-d)\left(\frac{\partial y_t}{\partial I_t} + p^I_t\right) \tag{9a}$$

$$I_t = 0 \qquad \frac{\partial PV_t}{\partial K_{t-1}} \leq (1-d)\left(\frac{\partial y_t}{\partial I_t} + p^I_t\right) \tag{9b}$$

Using equations (9) one period ahead and substituting them into equations (7) makes it possible to substitute out the unobservable dynamic shadow price, $\frac{\partial PV_{t+1}}{\partial K_t}$, giving the following expressions after some rewriting:

$$I_t > 0,\, I_{t+1} > 0 \qquad r_{t+1}E\left[(1-d)\left(p^I_{t+1} + \frac{\partial y_{t+1}}{\partial I_{t+1}}\right)\right] = p^I_t + \frac{\partial y_t}{\partial I_t} - (p_t - m_t)\frac{\partial F_t}{\partial K_t} \tag{10a}$$

$$I_t = 0,\, I_{t+1} > 0 \qquad r_{t+1}E\left[(1-d)\left(p^I_{t+1} + \frac{\partial y_{t+1}}{\partial I_{t+1}}\right)\right] \leq p^I_t + \frac{\partial y_t}{\partial I_t} - (p_t - m_t)\frac{\partial F_t}{\partial K_t} \tag{10b}$$

$$I_t > 0,\ I_{t+1} = 0 \qquad r_{t+1}E\left[(1-d)\left(p_{t+1}^I + \frac{\partial y_{t+1}}{\partial I_{t+1}}\right)\right] \geq p_t^I + \frac{\partial y_t}{\partial I_t} - (p_t - m_t)\frac{\partial F_t}{\partial K_t} \tag{10c}$$

Note that there is one case for which no expression can be obtained, viz. $I_t = 0$, $I_{t+1} = 0$. The reason is that inequality (9b) one period ahead combined with inequality (7b), does not allow substituting out the unobservable dynamic shadow price.

These combined first order conditions have the following interpretation. The right hand side sums up the marginal costs minus the marginal benefits of investing today. The marginal costs consist of the unit purchase price of capital and the marginal adjustment cost. The marginal benefit consists of the value of marginal product in year *t*, which is not obtained if investment takes place in year *t+1*. The left-hand side represents the expected discounted sum of marginal costs of investment in period *t+1*. So, essentially these first-order conditions are a comparison of marginal investment costs over two periods. If investment takes place in both periods *t* and *t+1*, the costs in both periods should be equal, as given in equation (10a). The case of no investment in year *t* and positive investment in year *t+1*, case (10b), corresponds with higher marginal costs of investment in year *t* compared to *t+1* whereas for (10c) the opposite holds.

The impact of the production constraint on investment follows from the term $m_t \frac{\partial F_t}{\partial K_t}$. With the Lagrange multiplier being non-negative by definition and the marginal product of capital expected to be positive from production theory, the total term is expected to be positive. Therefore, for a given expected marginal investment cost in year *t+1* and with a binding constraint on production ($m_t>0$), the equilibrium condition holds for a smaller level of investment compared to a situation without a constraint on production. So, from this theoretical model it follows that optimal investment is reduced in the presence of a binding constraint on production.

Empirical model and estimation

Empirical analysis proceeds by estimating the first-order conditions derived from the theoretical model directly. However, since conditions (10b) and (10c) contain inequality signs and since no expression could be obtained for the case of zero investments in two subsequent years, only equation (10a) is estimated. As shown below, this implies a sample selection problem that has to be corrected for. Other issues that are dealt with in this section are the specification of functional forms for the production function and the adjustment cost function and the specification of the expectations formation process. Furthermore, the panel nature of the data has to be accounted for in estimation. Finally, the unobservable Lagrange multipliers m_{ht} have to be dealt with. After expounding the estimation method a testing procedure is described that allows for testing whether the constraint on production, arising from manure policies, was binding or not.

For the production function a quadratic functional form with two variable inputs (feed and other variable inputs), one aggregated quasi-fixed capital good (consisting of buildings, machinery and equipment) and three fixed factors (family labor, land and technological change) is used:

$$F\left(x_{h,t}\right) = a_{0,h} + \sum_{i=1}^{6} a_i x_{i,h,t} + \tfrac{1}{2}\sum_{i=1}^{6}\sum_{j=1}^{6} a_{ij} x_{ih,t} x_{jh,t} \tag{11}$$

where $x_{i,h,t}$ denotes respectively aggregated capital (i=1), feed input (i=2), other variable input (i=3), labour (i=4), land (i=5) and technological change (i=6).

For the adjustment cost function a flexible specification is used:

$$y\left(I_{h,t}\right) = b_1 I_{h,t} + \tfrac{1}{2} b_2 I_{h,t}^2 + \tfrac{1}{3} b_3 I_{h,t}^3 \tag{12}$$

Whited (1998) favored a flexible specification over the standard quadratic adjustment cost function using a sample of U.S. manufacturing firms. He found that a quadratic specification resulted in negative adjustment cost, whereas the flexible specification restored the positive

relation between investment and adjustment costs. Moreover, specification testing did not reject the flexible specification. An advantage of this flexible specification is that it allows for a variety of different adjustment cost functions (e.g. linear, quadratic, asymmetric adjustment costs). For this function to be convex in investment the second derivative with respect to investment, $y_{II}(I_{h,t}) = b_2 + 2b_3 I_{h,t}$, has to be greater than zero.

Assuming rational expectations, the unobserved expected values of *t+1* variables are replaced by their realized counterparts and an expectation error e_{t+1} that captures the difference between the expected and realized values is added. Using the first order derivative of (11) with respect to capital and the first order derivative of (12) with respect to investment and substituting them into (10a), the following expression is obtained after some rewriting:

$$(1-d)r_{t+1}\left(b_1 + b_2 I_{h,t+1} + b_3 I_{h,t+1}^2 + p_{t+1}^{I^+}\right) - b_1 - b_2 I_{h,t} - b_3 I_{h,t}^2 - p_t^{I^+} + \left(p_t - m_{h,t}\right)\left(a_1 + \sum_{j=1}^{6} a_{1j} x_{h,j}\right) = e_{h,t+1} \tag{13}$$

Properties of these errors are that $E(e_{h,t+1}) = 0$, $E(e_{h,t+1}^2) = s_{h,t+1}^2$ and that $e_{h,t+1}$ is uncorrelated with any time *t* information. However, although expectations on period *t+1* variables are orthogonal to the expectation errors since they are a function of period *t* variables, their realized *t+1* values are not. Therefore, OLS estimates will be inconsistent and an instrumental variable estimator is necessary. In principle any period *t* variable can be used as an instrument. The Generalized Method of Moments (GMM; for an overview see Mátyás, 1999) is used to estimate (13) since it directly uses the above orthogonality conditions in the estimation procedure. Period *t* information is used in a vector of instruments $z_{h,t}$ and the moment condition is rewritten as $E_{h,t}(z_{h,t} \cdot e_{h,t+1}) = 0$, where $e_{h,t+1}$ is defined in (13).

The panel nature of the data used allows for adding farm-specific effects to the error term. These farm-specific effects are assumed to be fixed and may reflect farm-specific differences in marginal adjustment costs or farm-specific expectation errors. To remove the fixed effects

equation (13) must be estimated in first-differences. Taking first-differences implies that the linear term of the adjustment cost function is removed. It also implies that the choice of instruments is limited. Period *t* variables are now correlated with the first-differenced expectation errors and are therefore no longer valid instruments. The moment condition now becomes $E\left(z_{h,t-1}\Delta e_{h,t+1}\right)=0$ where Δ denotes first-differences. Valid instruments in GMM estimation with panel data consist of period *t-1* and earlier values of model variables (Arellano and Bond, 1991). The instrument set consists of two and more periods lagged values of investment, investment squared, the purchase price of capital, the output price, the price of feed, the price of other variable input and quantities of capital, family labor and land and technological change.

As shown in section two, the inter-temporal optimality conditions only yields an equality condition if investment is non-zero in both periods *t* and *t+1*. Therefore, following Alonso-Borrego (1998), estimation is conditioned on the event $D_{h,t+1}=\Gamma\left(I_{h,t+1}\cdot I_{h,t}\neq 0\right)=1$, where $\Gamma(.)$ is the indicator function, which takes value one if the condition is true and zero otherwise. The corresponding sample selection rule is defined as:

$$\begin{aligned} D_{h,t+1}&=1 \qquad if\ D^{*}_{h,t+1}=gZ_{h,t-1}+x_{h,t+1}>0 \\ D_{h,t+1}&=0 \qquad if\ D^{*}_{h,t+1}=gZ_{h,t-1}+x_{h,t+1}\leq 0 \end{aligned} \tag{14}$$

where $D_{h,t+1}$ is a latent variable, γ a vector of parameters and $x_{h,t+1}$ the residual of the selection equation. Under this conditioning event, the population moment condition is partitioned as:

$$\begin{aligned} E\left(z_{h,t-1}\Delta e_{h,t+1}\right)&=E\left(z_{h,t-1}\Delta e_{h,t+1}\mid D_{h,t+1}=1\right)\cdot \Pr\left(D_{h,t+1}=1\right) \\ &\quad +E\left(z_{h,t-1}\Delta e_{h,t+1}\mid D_{h,t+1}=0\right)\cdot \Pr\left(D_{h,t+1}=0\right)=0 \end{aligned} \tag{15}$$

From the partitioning it follows that the moment condition, conditional on $D_{h,t+1}$=1 differs from the population moment condition and in general cannot expected to be zero since it only represents part of the distribution of expectation errors. Using the above partitioning of the population moment condition (15), the conditional moment condition is rewritten as:

$$E\left(z_{h,t-1}\Delta e_{h,t+1} \mid D_{h,t+1}=1\right)=-E\left(z_{h,t-1}\Delta e_{h,t+1} \mid D_{h,t+1}=0\right)\frac{\Pr\left(D_{h,t+1}=0\right)}{\Pr\left(D_{h,t+1}=1\right)}=$$
$$-z_{h,t-1}E\left(\Delta e_{h,t+1} \mid x_{h,t+1}\le -gZ_{h,t+1}\right)\frac{\Pr\left(x_{h,t+1}\le -gZ_{h,t+1}\right)}{1-\Pr\left(x_{h,t+1}\le -gZ_{h,t+1}\right)}=-z_{h,t-1}s\ \frac{f\left(-gZ_{h,t+1}\right)}{1-\Phi\left(-gZ_{h,t+1}\right)} \tag{16}$$

where s is the covariance between $\Delta e_{h,t+1}$ and $x_{h,t+1}$ (normalized by the variance of $x_{h,t+1}$), $f\left(-gZ_{h,t+1}\right)$ is a normal density function and $\Phi\left(-gZ_{h,t+1}\right)$ is a normal distribution function. The ratio $f\left(-gZ_{h,t+1}\right)/\left(1-\Phi\left(-gZ_{h,t+1}\right)\right)$ is the Inverse Mill's ratio, which is denoted as $l_{h,t+1}$. Correcting for sample selection bias, the following moment condition is assumed to hold:

$$E\left(z_{h,t-1}\left(\Delta e_{h,t+1}-s\,l_{h,t+1}\right) \mid D_{h,t+1}=1\right)=0 \tag{17}$$

Substituting the $l_{h,t+1}$ by consistent estimates based on reduced-form probit estimates, equations (17) are estimated using GMM. Since it is not possible to estimate a fixed effects probit model (Maddala, 1987), the farm-specific effects cannot taken into account in calculating the Inverse Mill's ratio. Define $f_{h,t}\left(y_h,q\right)=z_{h,t-1}\left(\Delta e_{h,t+1}-s\,l_{h,t+1}\right)$, where y_h is a vector of all model variables and instruments in (17) for farm h and q is the vector of parameters to be estimated, and define $f\left(y,q\right)=\left[\frac{1}{H}\sum_{h=1}^{H} f_{h1}\left(y_h,q\right),\ldots,\frac{1}{H}\sum_{h=1}^{H} f_{h,T-1}\left(y_h,q\right)\right]$, then $\hat{q}_{GMM}$ is the estimator that minimises the objective function:

$$Q(q)=f\left(y,q\right)'V^{-1}f\left(y,q\right) \tag{18}$$

where V^{-1} is a weighting matrix. The GMM estimator is particularly apt for equations like (17). It can handle non-linear equations and allows for heteroskedastic errors.

In the equation to be estimated the unobserved Lagrange multipliers $m_{h,t}$, corresponding to the constraint on production, are present. An approach that is often applied in the literature on borrowing constraints (see e.g. Whited, 1992; Hubbard and Kashyap, 1992) is to assume that the unobservable Lagrange multipliers are a linear function of some observable variables and to substitute this function into the Euler equation. If borrowing constraints are present then the

parameters of the substituted function should be significant and a reduction in the value of the GMM objective function should be observed. However, instead of this (arbitrary) substitution of the unobservable Lagrange multipliers by related variables, in this paper the presence of binding constraints on production in the Euler investment equation is directly tested for. The testing procedure is based on structural stability tests for GMM developed by Hall and Sen (1999).

In order to explain the testing procedure, equation (13) is rewritten so that the product of the Lagrange multiplier with the marginal product of capital is on the right-hand side:

$$\begin{aligned}(1-d)r_{t+1}\left(b_2 I_{h,t+1} + b_3 I_{h,t+1}^2 + p_{t+1}^I\right) - b_2 I_{h,t} - b_3 I_{h,t}^2 - p_t^I + p_t\left(a_1 + \sum_{j=1}^{6} a_{1j} x_{h,j}\right) = \\ e_{h,t+1} + m_{h,t}\left(a_1 + \sum_{j=1}^{6} a_{1j} x_{h,j}\right)\end{aligned} \tag{19}$$

Since interest is in the potential constraining effects of the system of manure production rights introduced in 1987, the constraint on production is assumed to be present from 1987 on. In the years before 1987, the Lagrange multiplier is assumed to be zero. So, estimation before 1987 is straightforward using the left-hand side in estimation. If from 1987 on the constraint is not binding for farms, estimation does not differ from the period before 1987 since the left-hand side of (19) again defines the expectation error in the moment condition. However, if the constraint is binding for farms over a number of years, the left-hand side of (19), which determines $e_{h,t+1}$ in the unconstrained case, cannot be expected to be zero anymore, due to the presence of the positive Lagrange multiplier. Therefore, a natural way of testing for the presence of a production constraint is to test whether or not the moment conditions, based on the left-hand side of (20), hold before and after 1987. This is similar to testing whether the overidentifying restrictions hold before and after 1987 because if the production constraint is present and binding after 1987, a model that does not take this constraint into account is misspecified[3]. So, the null hypothesis states that the overidentifying restrictions hold both

before and after the structural breakpoint 1987[4], which is similar to the hypothesis that the constraint on production was not binding. The alternative is that the overidentifying restrictions do not hold in the period after 1987, which may have been caused by the binding constraint on production. The test statistic is defined as $J = J1 + J2$ where $J1$ and $J2$ are the J-test statistics from the overidentifying restrictions test for respectively the period before and after 1987. Under the null hypothesis that the overidentifying restrictions hold in both periods the test statistic follows a c^2 distribution with degrees of freedom equal to twice the number of overidentifying restrictions (Hall and Sen, 1999).

Data

Data on specialized pig farms covering the period 1980-1996 are obtained from a stratified sample of Dutch farms keeping accounts on behalf of the Dutch Agricultural Economics Research Institute (LEI) farm accounting system. Farms were selected if the share of pig output in total output exceeds 80%. The farms remain in the panel for about five to seven years, so the panel is unbalanced.

An implicit value for capital is obtained by dividing the sum of capital invested in buildings, machinery and equipment by a Tornquist price index. Capital investment is defined as the sum of investments and dis-investments. In estimation the discount factor and the depreciation rate are considered constant. The discount factor used is based on the average real interest rate over the estimation period and equals 0.95. The depreciation rate for capital is assumed to be 5%. The first-order derivative of the production function with respect to capital contains two variable inputs, pig feed and other variable inputs (e.g. veterinary costs, heating, electricity, hired labor and various other costs) and capital, family labor, land and technological change. The output price is a Tornquist price index calculated with prices obtained from LEI/Statistics Netherlands (several years). The implicit quantity of capital is

measured at constant 1980 prices, total farm family labor is measured in hours and land is measured in hectares.

Taking first differences and using twice-lagged values of endogenous variables implies that only farms with three or more observations can be used in estimation and that data for 1980 and 1981 can only be used as instruments. Removing farms with one or two observations and 13 observations with negative investments results in a data set with 882 observations on 281 farms. Basic statistics of the data are given in table 1.

INSERT TABLE 1

Table 2 gives averages for investment for the three periods of interest in this study: the period before the introduction of the manure production rights (1980-1986), the period in which these non-tradable rights were introduced (1987-1993) and the period in which these rights were made tradable to some extent (1994-1996). Looking at sample averages for investment as given in table 2 suggests that the system of manure production rights has reduced investments.

INSERT TABLE 2

As shown in the first column of table 2, average investment does not differ much for the first two periods but it is considerably higher in the period 1994-1996. However, looking at investment only does not take the ongoing increase in scale of farms into account. Therefore in the second column the investment/capital ratio is given. This ratio suggests that investment was considerably lower in the period 1987-1993 than in the other two periods. The higher investment/capital ratio in the period 1994-1996 suggests that the limited tradability of the

manure production rights in this period raised investments again. Although the observed pattern of average investment is what would be expected, this does not necessarily imply that the observed pattern is due to restrictions imposed by manure policy. Other variables could be the real underlying cause (e.g. low output prices). The model developed in the previous two sections takes into account the various variables that have an impact on investment and can therefore provide a better answer to the question whether manure policy has restricted investment than looking at the averages in table 2.

Results

In this section estimation results and the results of the testing procedure for production constraints are discussed. In order to control for sample selection bias, arising from using only observations with positive investment in the estimation of the inter-temporal optimality condition (14), first a probit reduced form is estimated for the event $D_{h,t+1}$=1. In order to have the Inverse Mill's ratio uncorrelated with the prediction error, two-, three- and four-period lagged variables are used in this reduced probit estimation. Using these parameter estimates, the Inverse Mill's ratio is calculated for observations with positive investment in two consecutive periods and is included in the Euler equation as additional regressor. Parameter estimates for the Euler equation over the whole period 1982-1996 are given in the first column of table 3.

INSERT TABLE 3

For the total sample period 5 of the 11 parameters are significant at the 5% level. The parameters from the marginal product of capital (a_{ij}'s) that are significantly different from zero at the 5% level have the following interpretation. The value marginal product of capital

is increasing in the stock of capital (parameter not significantly different from zero at 5% level), feed input (significant), labor and land (both not significant). It is decreasing in output price (not significant), other variable inputs (significant) and technological change (significant). From equation (13) it follows that a high marginal product of capital has a positive effect on investment in period *t*. So, large quantities of capital, feed, labor and land have a positive effect on investment in period *t*, whereas the output price, other variable inputs and technological change have a negative effect on investment. Although they are not significant at the 5% level, especially the signs of the stock of capital and the output price are opposite to their expected signs. Using the parameters a_{ij} it can also be checked whether the production function is increasing in capital for all observations. It appears that for only 50% of the observations this theoretical restriction holds. The parameter estimates for the adjustment cost function are not in accordance with standard adjustment cost theory. The negative parameter for the quadratic term (significant at the 5% level) suggests that marginal adjustment costs are decreasing over a large range. Due to the positive cubic term (not significant) marginal adjustment costs will eventually rise again. Whether adjustment costs are positive over the whole range depends upon the linear adjustment cost term. However, this was removed by first-differencing and it is not possible to calculate this parameter *ex post* since it cannot be separated from the average of the farm-specific effect. The implication of the non-linear adjustment cost terms is that for a large range of investments it is optimal to invest more than the observed quantity, since marginal adjustment costs are decreasing in this range. That farmers do not invest more may be due to restrictions (e.g. credit restrictions or restrictions imposed by the (local) government) preventing them from investing optimal quantities. The parameter of the Inverse Mill's ratio is significant at the 5% level, indicating that using only positive observations without correction using an Inverse Mill's Ratio, yields biased estimates due to sample selection.

The impact of manure production rights

The *J*-statistic, which is the test statistic for testing whether the overidentifying restrictions hold, has a value of 22.07, which is smaller than the critical $c^2_{20;0.95}$ level of 31.41. This indicates that the model is not misspecified for the whole period. This suggests that for the whole sample period, a model without a binding constraint on production could be used to explain investment behavior. However, since the constraint was already absent for a number of years and since it may not have been binding throughout the whole period 1987-1996, it is worthwhile to look at the model estimates for the subsamples 1982-1986 and 1987-1996 and test for a structural break in 1987.

To perform this test the sample is split over the periods 1982-1986 and 1987-1996. The model is re-estimated for both periods and the parameter estimates for the respective periods are given in column two and three of table 3. For the period 1987-1996, the parameter estimates do not differ much with respect to size, sign and significance from those for the total sample period, so that interpretation of the parameters is the same. The *J*-statistic of 41.86 however indicates misspecification of the model in this case. The estimates for the period 1982-1986 are somewhat different however. The value marginal product of capital is now increasing in output price, the stock of capital and technological change with all three parameters significantly different from zero. High output prices, a large stock of capital and a high state of technology have positive effects on investment in period *t*. Feed input (significant), other variable input, labor and land (all three not significant) have a negative effect on period *t* investment, through the value marginal product of capital. Using parameters and data for this period shows that production is now increasing in capital for all observations. The positive and significant parameter a_{11} indicates that there are increasing marginal returns of capital in production. Parameter estimates for the adjustment cost function are again negative for the quadratic term and positive for the cubic term, both not significant at the 5%

level, however. The *J*-statistic of 31.78 indicates that the model is only just rejected at the 5% level of significance (critical value is 31.41).

In order to test for a structural break between the periods 1982-1986 and 1987-1996 the test statistic is calculated by adding up the two values of the *J*-test statistics of both subsample estimations, yielding a structural break test statistic of 73.64, which is larger than the critical level of $c^2_{40;0.95}$ = 55.76. Therefore, the null hypothesis that the overidentifying restrictions hold before and after the breakpoint, i.e. the model is correctly specified before and after 1987, is firmly rejected. In other words, the hypothesis that manure productions rights did not have a constraining effect on production, affecting investment decisions of farmers, is rejected. The individual overidentifying restrictions tests suggest that before 1987 the model is correctly specified and that after 1987 the model is misspecified.

It is interesting to test whether the change in the system of manure production rights from non-tradable to tradable manure production rights relaxed the constraint on production. If this is true, the model would be rejected for the period 1987-1993 and not rejected for 1994-1996. Therefore the model is also estimated using these subsamples. The results are given in the fourth and fifth column of table 3. For the period 1987-1993 the model is firmly rejected with a *J*-statistic of 58.37. For the period 1994-1996, the *J*-statistic yields the considerably lower value of 36.72, which still indicates rejection of the model at the 5% level of significance. The structural break test statistic has a value of 95.10, indicating that the overidentifying restrictions do not hold both before and after 1994. The lower *J*-test statistic for the period 1994-1996 however suggests that the production constraint may have become less binding in the latter period due to tradability of the manure production rights.

Borrowing constraints

The results provide evidence for the presence of binding constraints on production arising from the manure policies implemented in 1987 and a relaxation of this constraint in 1994. However, it could well be that the structural break found in 1987 has other causes. In the literature, rejection of the overidentifying restrictions has often been attributed to the presence of borrowing constraints that are not taken into account in this model (Whited, 1992; Hubbard and Kashyap, 1992). It might well be that rejection of the model for the period 1987-1996 is due to the presence of borrowing constraints that were absent in the period 1982-1986. The financial position of farms may have worsened so that it was harder to obtain loans or banks may have become more risk averse in supplying funds due to rising uncertainty about the viability of the pig sector.

Extending the model by explicitly including borrowing constraints gives the same problem as the presence of production constraints. If the borrowing constraint is binding, another unobservable Lagrange multiplier is introduced in the model. A more simple procedure is to split the 1987-1996 sample into a set of farms which is expected to be financially constrained, and a set with farms that are not. Therefore, a debt-asset ratio is calculated for each farm and farms with a debt-asset ratio higher than 70% are separated from the sample. A debt-asset ratio of 70% and higher is usually seen as critical in obtaining loans (Mulder, 1994: 115). Debts are defined as the sum of long term loans and short-term debts and the asset value is the total balance value of assets. This yields a dataset containing 396 observations on 149 farms with a debt-asset ratio lower than 70%, which are considered not to be financially constrained. Only 33 farms (78 observations) had a higher debt-ratio and 8 out of 190 farms present in this period had no observations on debts and loans. The dataset with farms that are expected not to be financially constrained was used to estimate the model for the period 1987-1996. If borrowing constraints were the real underlying cause of the rejection of the model in this

period, then the model should not be rejected using this sample. However, the *J*-test statistic for this estimation has a value 35.00, which still leads us to reject the model for this period. So, this indicates that borrowing constraints are not the underlying cause for model rejection in the period 1987-1996.

Conclusions and discussion

The objective of this paper is to assess whether manure production rights had a significant constraining effect on capital investment in the Dutch pig sector over the period 1987-1996. In order to answer this question an inter-temporal model of investment is developed, which is augmented by a (potentially binding) constraint on production arising from the introduction of manure production rights. The model developed in this paper provides an explanation for the occurrence of zero investments by assuming that investment is zero for the range in which the marginal benefits of investing are equal to or smaller than the purchase price of capital leading to regimes for zero and positive investments.

In the theoretical model it is shown that a constraint on production implies a reduction in investment. Furthermore, the empirical model shows that testing for the presence of these constraints is straightforward using a GMM structural break test. If a binding constraint on production was present in the period 1987-1996, then the unrestricted model is misspecified, since the constraint is not taken into account. Direct modeling of the restricted model with a binding constraint on production is not possible due to the unobservable Lagrange multiplier.

Although the model is not rejected for the whole sample period, its estimates are not satisfactory. Parameter estimates for both the production function and the adjustment cost function are not in accordance with theory. Estimates using the pre-manure production rights period (1982-1986) sample however, are in line with theory, whereas the estimates for the manure production rights period (1987-1996) are comparable to those for the whole sample.

Using a GMM test for a known breakpoint provides evidence for the presence of a structural break in 1987, supporting the hypothesis that manure policy has reduced investments and therefore affected the long-run development of the Dutch pig sector. Estimating the model for the periods 1987-1993 and 1994-1996 and applying this test for the year 1994, in which manure production rights became tradable, shows that the constraint on production became less binding due to the tradability of manure production rights.

Although the presence of a structural break in 1987 was demonstrated, this does not automatically mean that this was caused by a binding constraint on production arising from manure policy. There can be other sources for model rejection in the manure policy period such as borrowing constraints or other aspects of the investment process that are not taken into account in the model. Therefore, one should be careful with using the results. However, using a subsample of farms that are not expected to be financially constrained still leads us to reject the model for the period 1987-1996, which confirms the conclusion that manure production rights affected investment processes negatively through its effects on production.

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Table 1 Mean and standard deviation of variables used in chapter five

Variable	Dimension/Base year	Symbol	Mean	Standard Deviation
Quantities				
Capital investment	100.000 Dutch guilders of 1980	I	0.515	1.095
Capital	100.000 Dutch guilders of 1980	x_1	5.673	4.093
Pig feed	100.000 Dutch guilders of 1980	x_2	4.479	3.198
Other variable input	100.000 Dutch guilders of 1980	x_3	1.320	1.021
Farm family labour	1000 hours	x_4	3.465	1.356
Land	Hectares	x_5	8.470	9.767
Technological change	Trend, 1980=1	x_6	10.921	4.226
Price indices				
Capital	Base year 1980	p^I	1.239	0.101
Pig output	Base year 1980	p	1.069	0.191

Period: 1980-1996.

Observations: 882

Table 2 *Sample averages for investment and investment/capital ratio (standard deviations in parentheses)*

Period	Sample average I_t	Sample average I_t/K_t	N
1980-1986	0.496 (0.991)	0.099 (0.194)	225
1987-1993	0.474 (1.100)	0.078 (0.143)	445
1994-1996	0.621 (1.183)	0.094 (0.190)	212
Total	0.515 (1.095)	0.088 (0.169)	882

Table 3 Parameter estimates for the Euler equation (standard errors in parentheses)

	1982-1996	1982-1986	1987-1996	1987-1993	1994-1996
α_1	-0.136 (0.092)	0.214 (0.052)*	-0.042 (0.078)	-0.179 (0.030)*	0.045 (0.016)*
α_{11}	0.006 (0.005)	0.013 (0.005)*	0.001 (0.003)	0.020 (0.005)*	$1.9*10^{-4}$ (0.001)
α_{12}	0.047 (0.017)*	-0.039 (0.011)*	0.030 (0.010)*	-0.010 (0.005)*	0.003 (0.001)*
α_{13}	-0.056 (0.029)*	-0.019 (0.029)	-0.032 (0.019)	0.006 (0.014)	-0.001 (0.002)
α_{14}	0.023 (0.017)	-0.013 (0.009)	0.017 (0.014)	-0.016 (0.006)*	0.001 (0.002)
α_{15}	0.002 (0.004)	-0.006 (0.004)	0.001 (0.002)	-0.003 (0.001)*	$2.0*10^{-4}$ ($1.9*10^{-4}$)
α_{16}	-0.010 (0.005)*	0.030 (0.004)*	-0.012 (0.005)*	0.019 (0.002)*	-0.005 (0.001)*
β_2	-0.025 (0.008)*	-0.006 (0.005)	-0.001 (0.008)	-0.028 (0.006)*	0.007 (0.001)*
β_3	0.001 (0.001)	0.001 (0.001)	$2.0*10^{-4}$ (0.001)	0.002 (0.001)	$4.7*10^{-4}$ ($9.5*10^{-5}$)*
σ	-0.022 (0.010)*	0.101 (0.011)*	-0.033 (0.010)*	0.043 (0.007)*	-0.017 (0.002)*
J-statistic (d.f.)	22.07 (20)	31.78 (20)	41.86 (20)	58.37 (20)	36.73 (20)
N	650	165	485	333	152

* Significant at the 5% level

[1] Other elements in the legislation are concerned with the application of manure and requirements on animal housing.

[2] The number of dis-investments in the dataset used is small. In total there are 13 dis-investments out of 1662 observations. An explanation for this particularly low number is that farmers who sell their buildings or equipment are likely to quit farming and therefore leave the dataset.

[3] For a discussion on identifying and overidentifying restrictions see Hall (1999).

[4] Hall and Sen (1999) provide a rigorous technical discussion on structural break tests in GMM estimation. By decomposing the population moment restrictions into identifying and overidentifying restrictions, they derive a test for parameter stability and a test for model misspecification due to a structural breakpoint.